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FREQUENCIES OF SPIRAL AND GREEN-BONE FRACTURES ON UNGULATE LIMB BONES IN MODERN SURFACE ASSEMBLAGES

Gary Haynes

During observational fieldwork in undisturbed ranges of free-roaming bison and moose, I have identified approximately 8% of surface bones as spirally or green-fractured due to documented carnivore activity, and 5% as spirally or green-fractured due to trampling or dust wallowing by bison. The bones of smaller species suffer up to 50% breakage. Bone modifications by wild wolves and bears are briefly described, as are characteristics of fractures caused by trampling and wallowing.

Prehistorians and paleoecologists for decades have been attempting to make interpretive statements about fractured mammalian bones whose modifications may or may not be cultural in origin. Well-known examples are Dart (1957, 1964) on the so-called osteodontokeratic technology of australopithecines; Breuil (1938, 1939), P‘ei (1938), and Black et al. (1933) on bone modifications in Choukoutien Cave assemblages; and Morlan (1979, 1980), Bonnichsen (1979), and Jopling et al. (1981) on a hypothesized bone-working technology found in early and pre-Wisconsinan Beringia. Interpretations of this latter hypothesized industry are especially disputed by some scholars (see the exchange by Bonnichsen [1981] and Guthrie [1980, 1981]).

Some researchers consider spiral fractures to be diagnostic of human activity. Recently Myers et al. (1980) reported on a high proportion of spiral fractures in North American mammalian bone assemblages of Miocene, Pliocene, and Pleistocene age. Many of the materials described by Myers et al. (1980) date to time periods from which nearly no serious prehistorians expect to find traces of human beings in North America. Myers et al. (1980) argue that ungulate trampling reasonably accounts for long bone spiral fracturing, and that therefore human agency in bone fracturing is not necessarily demonstrated by the simple existence of spiral breaks.

Concerned researchers have made the point that nonhuman agencies could be responsible for some types of bone modifications, and that we must document what these modifications are or could be so that we do not mistakenly interpret noncultural materials as having been affected by human behavior (Stanford 1979; Binford 1981). Such documentation has been the goal of my research over the last four years (1977–1981). The work involved field observations of the behavior and movements of large North American predators such as Canis lupus (Timber wolf) and Ursus spp. (bears) and their prey, mainly Bison bison, Alces alces (moose), and Odocoileus virginianus (whitetail deer) in north-central Canada and the Great Lakes region (Figure 1), as well as in numerous national parks and preserves throughout North America. Carcasses and skeletal remains from dated predation and catastrophic deaths have been seasonally reexamined, and complete records have been made of the effects of weathering on bones.

Table 1 presents data on sites investigated in the fieldwork, and Table 2 presents data on bone-feeding experiments involving captive animals at the National Zoological Park in Washington, D.C. Complete descriptions of the experiments are in Haynes (1981). The purpose of the experiments was to allow formulation of bone-gnawing models and to document end-effects of gnawing by large cats, bears, hyenas, and canids. Data in the two tables provide the base for synoptic discussions below.

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Figure 1. Map of main study areas and prey species of main concern.
Table 1. Carcass and Skeletal Sites.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number Adults (&gt; 3 yrs.)</th>
<th>Number Subadults</th>
<th>Remarks and Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odocoileus spp.</td>
<td>8</td>
<td>3</td>
<td>Suspected wolfkills, N.E. Minn. and British Columbia.</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
<td>Confirmed wolfkills, N.E. Minn.</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>Only scavenged, British Columbia and Wood Buffalo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>National Park</td>
</tr>
<tr>
<td>Cervus canadensis</td>
<td>1</td>
<td>1</td>
<td>Confirmed wolfkills, Riding Mntn. National Park.</td>
</tr>
<tr>
<td>Alces alces</td>
<td>9</td>
<td>4</td>
<td>Confirmed wolfkills, Isle Royale National Park.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>Suspected wolfkills, Riding Mntn. National Park and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Isle Royale National Park</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>Only scavenged, Isle Royale National Park</td>
</tr>
<tr>
<td>Bison bison</td>
<td>16</td>
<td>10</td>
<td>Confirmed wolfkills, Wood Buffalo National Park.</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0</td>
<td>Suspected wolfkills, Wood Buffalo National Park</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>7</td>
<td>Drowned, Wood Buffalo National Park</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>Poached, disease, other death, Wood Buffalo National</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Park</td>
</tr>
<tr>
<td>Ursus americanus</td>
<td>2</td>
<td>0</td>
<td>Eaten by wolves, Wood Buffalo National Park</td>
</tr>
<tr>
<td>Canis lupus</td>
<td>3</td>
<td>1</td>
<td>Killed by wolves, not eaten, Wood Buffalo National Park</td>
</tr>
<tr>
<td>Vulpes vulpes</td>
<td>1</td>
<td>0</td>
<td>Killed by wolves, not eaten, Wood Buffalo National Park</td>
</tr>
</tbody>
</table>

In the following discussions, a long bone is defined as spirally fractured if the fracture outline curves as a helix, partial helix, or combination of helixes around the shaft (Figure 2), and the fracture occurs in the part of the shaft enclosing marrow and not in trabecular bone tissue.

CARNIVORE GNAWING AND BONE FRACTURING

When large carnivores gnaw on long bones from animals the size of adult bison or moose, they seldom, if ever, successfully crush the elements to fragments between their jaws. Large long bones are gnawed first at an epiphysis, and as the cancellous tissue is consumed the bone shaft may be entirely opened up at one or both ends (see Bonnichsen [1973]). Cached or scavenged bones may be gnawed first on shafts rather than epiphyses (Figure 3). When carcass utilization is

Table 2. Captive Carnivore Feeding Experiments.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number Animals</th>
<th>Number Long Bones Fed</th>
<th>Hours Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canis lupus</td>
<td>2</td>
<td>5</td>
<td>0.30</td>
</tr>
<tr>
<td>Fennecus zerda</td>
<td>6</td>
<td>1</td>
<td>0.15</td>
</tr>
<tr>
<td>Vulpes macrotis</td>
<td>2</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Helarctos malayanus</td>
<td>3</td>
<td>3</td>
<td>0.25</td>
</tr>
<tr>
<td>Tremarctos ornatus</td>
<td>3</td>
<td>2</td>
<td>0.50</td>
</tr>
<tr>
<td>Ursus arctos</td>
<td>2</td>
<td>2</td>
<td>0.45</td>
</tr>
<tr>
<td>U. arctos middendorffi</td>
<td>3</td>
<td>11</td>
<td>3.25</td>
</tr>
<tr>
<td>U. americanus</td>
<td>1</td>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>U. maritimus</td>
<td>2</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Martes pennanti</td>
<td>1</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Crocuta crocuta</td>
<td>2</td>
<td>15</td>
<td>1.05</td>
</tr>
<tr>
<td>Panthera leo</td>
<td>9</td>
<td>3</td>
<td>0.50</td>
</tr>
<tr>
<td>P. onca</td>
<td>2</td>
<td>3</td>
<td>0.15</td>
</tr>
<tr>
<td>P. tigris</td>
<td>2</td>
<td>3</td>
<td>—</td>
</tr>
</tbody>
</table>
unusually heavy, bones are broken by leverage with the teeth (Figure 4). Many shaft fragments may not be consumed or gnawed, so they will lack signs of crunching, tooth perforations, or gnawing, and could be mistaken for artifactual. However, except at homesites and scavenged sites, complete bone fragmentation is rarely done by the wolves preying on bison and moose in the study areas. Adult bison bones found at dens or other sites where wolf pups and adults socialize in summer may be spirally fractured but are almost always well marked by teeth (Figure 5). From time to time wolves move their pups to sites convenient to carcasses, creating temporary homesites in which bison or moose bones are typically a greater center of attention than they are elsewhere.

During gnawing by carnivores, the force of their levering, pulling, and biting down sometimes creates spiralling cracks through compact tissue, a kind of incomplete fracturing that is easily seen after slight weathering of the element (Figure 6a). Because such gnawed bones usually have an epiphysis missing and are structurally weakened, they are likely to fracture when kicked or
trampled by large animals (Figure 6b), with the fracture directed at least partly along the spiralling crack lines.

Scavenging by Bears

Bears actively scavenge carcasses in spring and fall. Like other species of scavenger, bears prefer to eat meat, hide, viscera, or cartilage before finally gnawing bones. Black bears occasionally fracture long bones of adult bison, but do so more often because wolves have first gnawed off an epiphysis (usually the distal end of femora, the proximal end of humeri, or the proximal end of tibiae). While large bears are capable of breaking bison limb bones, it hardly seems adaptive for them to rely on such a difficult source of food. However, in years when there have been poor crops of berries or mast, bears would make stronger efforts to feed on all available carcass parts in the fall, and many long bones would be broken to get out marrow. Winter scavenging would also be heavy by bears in years when summer and fall foods were in poor supply.
Frequencies of Fractures

My sample includes 26 well documented wolf-killed bison whose bones weathered less than 36 months; 8% of the remaining long bone shafts (15 out of 180) were fractured, not all spirally, although all were fresh when broken (that is, less than 1 month old). Fourteen of the bones were from calves or yearlings, and 73% (11 out of 15) displayed identifiable tooth marks (as described in Haynes [1981: Chapters 4, 8, and 10]). Toothmarks on the other pieces would have been difficult to identify except by analysts experienced with carnivore assemblages.

A few long bones of adult moose have been found spirally or part spirally fractured, in all cases (7 out of 88 long bones in 12 sites) a result of secondary scavenging by wolves approximately 3 to 6
months after the moose were killed and fed upon by the same or other wolf packs. The fracture edges on larger scavenged fragments often show right-angle offsets, due to the presence of drying cracks in the bones before they were broken by gnawing animals (Haynes 1980a:Figure 9, specimen on far left). Nonetheless, fully spiral fragments up to 10 cm long have been found.

As with bison, many long bones from fully utilized subadult moose carcasses were fractured when still fresh. After wolves have abandoned the remains and bears have scavenged them, long bones may have been broken into three to eight fragments each, each greater than 5 cm long, with only one or a few exhibiting tooth markings.

In contrast, a much higher proportion of sites of predator-killed adult deer, caribou, antelope, sheep, and other medium-size species contain green-fractured long bones. Few fragments of these bones display any identifiable tooth markings (see Haynes [1980b]). In killsites of whitetail deer or animals of similar body size, up to 100% of the long bones may be fragmented; at least three long bones of the upper legs are commonly fragmented at sites of fully or moderately utilized carcasses.

It is conceivable that during times of prey scarcity, carnivores and scavengers would more often (and perhaps habitually) fragment larger bones. Alternatively, during the initial stages of intervals of extinction caused by rapid, unidirectional climatic change, herbivores might die in high numbers without predation, and the overabundant carcasses would be poorly utilized by scavengers. The final stages of extinction would then see a critically low number of prey carcasses being overutilized by starving carnivores, which eventually perish themselves.
On rare occasions wolves and other carnivores in these studies (Haynes 1978, 1980a, 1981) have forced flakes of cortical bone 10 cm or longer off long bone shafts. More often the flakes produced by carnivores measure 1 to 5 cm long. Many times flakelike fragments are broken off which retain, at least at one end, some of the periosteal and endosteal surfaces of the bone shaft and terminate with sharp edges at the distal end (Figure 4). These flakes or spalls may have flat proximal ends that appear grossly similar to striking platforms on artifactual materials, but gnaw damage is evident on the bone surface, and some edge rounding is usually present on the proximal end where teeth grasped the fragment. Flakes detached by carnivores, through pressure or leverage, may show hackle lines and ripple marks on ventral surfaces (see Crabtree [1972] and Bonnichsen [1977] for terminology).

It is possible that huge extinct animals such as Arctodus, a carnivorous bear (Kurtén 1967), could have levered off shaft fragments in an effort to get at marrow within long bones and created flakes or flakelike spalls that lacked tooth marks. In the case of large bones such as those of Mammutthus the effort required to break up fresh cortical tissue would have been enormous but probably not beyond the capabilities of hungry animals, especially on elements with epiphyses partly removed during earlier gnawing. Nonetheless, hypothetical gnawing by bears seems to me a far-fetched explanation for the existence of fragmented mammoth bones in any assemblage.

Other large carnivores such as Canis dirus may also have been capable of breaking up some mammoth bones by first gnawing through epiphyses, then levering back cortical bone. However, scavengers or predators must have been exceptionally hungry to have done so. Fractured edges of mammoth limb bones occasionally show carnivore tooth marks (a fractured ulna from Alaska is illustrated in Haynes [1981:Figure 43]), but I have not seen tooth marks on flakelike bone fragments in either the Pleistocene collections at the University of Alaska Museum or the Smithsonian Institution. The size and thickness of mammoth limb bones probably presented even the largest and hungriest Pleistocene scavengers with gnawing problems too formidable to allow fragmentation.

BONE FRACTURING BY TRAMPLING AND WALLOWING

Trampling by hoofed animals includes both inadvertent kicking and placement of the hoof directly upon an object on the surface of the ground. Kicked bones are moved several centimeters or more and thereby suffer impact, apparently of insufficient force to cause fracturing when the element is whole and fresh. Trampling bison herds can move articulated carcass remains many meters from the original places of deposition. But I have not seen fractures produced this way.
Figure 7. (Top) Bison femur proximal end broken by trampling after a few years of weathering in well drained grassland. (Bottom) Bison femur distal end broken in dust wallow after a few years of weathering. The fracture is spiral.
unless carnivores had first gnawed off an epiphysis. However, weathered and degreased limb bones, being much more brittle than fresh elements, often fracture when kicked or stepped on by large animals (Figure 7, top).

When bull bison wallow they kick all their hooves into and through the dirt in which they lie, using forefeet to scatter dust back over themselves. They also violently beat their horns backwards against the ground surface. These actions are brief but often repeated, especially in rutting season, so that bones situated on ground where bison excavate and use dust wallows are several times subject to powerful destructive forces (Figure 7, bottom). Wallowing also tends to move, bury, or expose once-buried bones.

The most common destructive effects of trampling and dust wallowing seen on bison ranges are splintering and crushing of ribs, vertebrae, and scapulae at the sites. Nasal bones and premaxillary bones may be kicked off skulls, and teeth are broken out of sockets. Mandibles may be segmented into the ascending ramus, the central cheek toothrow minus lower border, and the forward part of the ramus. Pelves may be broken in half or into several fragments, with bone surrounding the acetabulum surviving longest. Many elements are reduced to chips and unidentifiable splinters. Even though hardly fresh, many weathered long bones may be partially spirally fractured by trampling, that is, during Stage 1 to Stage 2 of the Behrensmeyer (1978) descriptive framework. Bones in this category possess sharp-edged longitudinal drying cracks, little or no soft tissue, and only minor peeling of periosteal bone tissue.

Weathered, spirally fractured long bones have been found in open and dry grassland, but they are more numerous in well shaded and moist areas such as woods, parkland, and thick grass-sedge meadows, or in wet areas such as pond and lake bottoms or stream crossings, where the deteriorating effects on bones of ex vivo weathering are considerably reduced, and where there is heavy bison traffic. Bones in the latter areas eventually disappear into the mud due to continued trampling (Figure 8). Many fractured bones possess a spiral fracture edge offset by a linear section of fracture edge (Figure 9), thus exhibiting attributes of two kinds of breakage.

Figure 8. Three bones of adult male Bison lying around edge of a sinkhole pond. Specimen “A” is a thoracic vertebra trampled into the mud, “B” is a right humerus embedded in mud atop willow roots, and “C” is a left humerus buried vertically up to the head.
Figure 9. Bison femur, distal end of shaft. Right edge has right-angle offset in fracture outline, caused by longitudinal fracture interrupting spiral fracture.

Frequencies of Fractures

The sites containing spirally fractured bones have ranged in postmortem age from 5 years to over 15 years. Of the total sample of 273 bones found in a Stage 1 to Stage 2 weathering condition (Behrensmeyer 1978) and fractured by trampling or wallowing, only 14 are fully spirally fractured, a frequency of 5%. This frequency holds only for bones of larger species such as bison or moose, because over 50% of the long bones from deer, caribou, bears, and similarly sized animals may be spirally fractured by being trampled.

DISCUSSION

Morlan (1980) argues that there are different kinds of spiral breaks on bones, not all of which need occur on fresh specimens. There are also different kinds of green bone breaks, not all of which need be spiral. Morlan (1980:Table 3.3) details some attributes that can distinguish green bone breaks from breaks in aged bones. The attributes associated with bones broken when fresh are (1) the presence of relatively smooth fracture surfaces; (2) presence of acute or obtuse angles formed by the intersection of fracture surfaces with outer surfaces of the shaft; and (3) no difference in the color of fracture surfaces and the surface of the outer compacta.

Myers et al. (1980) describe high frequencies of long bone spiral breaks in paleontological collections, but they do not explicitly apply Morlan’s criteria to the fossils they discuss, so the number of fractures classifiable as green-bone breaks according to Morlan’s key is not known. Apparently Myers et al. (1980) determined whether or not breaks occurred when elements were fresh only on the basis of spiral breaks, defined as the formation of an oblique outline on the fractured bone shaft (Myers et al. 1980:484). Such oblique fractures are “not at all rare” in fossil ungulate limb bone collections, “regardless of age” (Myers et al. 1980:487).

Since Myers et al. (1980) did not report total numbers of long bones for each collection considered, the proportions of all bones with spiral fractures are not indicated. It is possible that the proportions are high: 96 of 105 Equus tibiae from the Sheridan County collections are spirally
fractured, and if each bone represents one individual animal (out of about 500 individuals in the collections including mammoth, rodents, camel, and carnivores, besides the horses), then at least 20% of all individual animals found at the quarry provided a spirally fractured bone to the collections.

During my fieldwork, I carefully examined all bison and moose humeri, radius-ulnae, femora, tibiae, metacarpals, and metatarsals. Of my sample of 565 long bones, no more than 60 (or 11%) are partly or fully spirally fractured due to any agency such as gnawing, wallowing, or trampling, if "spirally fracturing" is defined most simply as an oblique fracture outline. No less than 33 bison and moose are represented by the spirally fractured elements, out of approximately 125 individuals, a frequency of 26% of individuals. Many of these bones show tooth marks from Canis or Ursus, but such marks might be overlooked by observers not experienced in identifying carnivore marks.

If I apply the three criteria that Morlan (1980:Table 3.3) indicates will separate green bone breaks from older bone breaks, and I eliminate bones showing easily identifiable tooth marks, then there are only 18 fractured bones which could still be mistaken for artifacts (see, for example, Figure 7); the elements are 2 metapodials, 4 femora, 1 tibia, 8 humeri, 1 radius, and 2 unidentified specimens, representing 17 individual animals, or about 14% of the total number of individuals and 3% of the total sample of long bones.

By far the greater part of the broken bones that I have examined in months of backcountry fieldwork are neither spirally fractured nor green fractured. In fact, most of them are fragmenting as they pass through advanced weathering stages and are characterized by multiple longitudinal cracks with rounding edges, exfoliation of periosteal tissue, and splintering of fracture edges, or in other words the general deterioration that eventually occurs in seasonally unfrozen surface bones anywhere in the world.

The higher proportions of spirally fractured specimens discussed by Myers et al. (1980) in paleontological collections may be due to the fact that the fauna dealt with contains species whose body sizes are smaller than bison and moose.

It is possible that the frequencies of spiral fractures I observed in modern bone assemblages are too low, because I may have failed to find large numbers of bones trampled into mucks and mud, especially in areas used most heavily by animals, such as watering holes and river crossings. These are the areas that preserve bones longer in near-fresh states and that also attract large numbers of trampling animals.

CONCLUSIONS

Modern bone assemblages from watering holes and traditional river crossings must be studied in detail, but even in the absence of such data it can be stated that any terrestrial bone assemblage predictably contains naturally broken items (in perhaps small but notable frequencies) which look like artifacts. Binford (1981) has independently arrived at similar conclusions.

It is recognized here that Morlan (1979, 1980), Bonnichsen (1979, 1981), and Irving (in Jopling et al. [1981]) are interpreting and explaining more than just spirally fractured bones of bison-sized or smaller species. Nonetheless, these kinds of fractured bones have been important in their discussions, and so must be carefully considered by any scholar interested in the issues. It is also recognized that simply because Binford (1981), Myers et al. (1980), and myself (Haynes 1981) have demonstrated the fact that natural agencies could have been responsible for breaking some bones with certain characteristics, we have not disproven that humans broke bones with the same characteristics. More detailed and persuasive arguments must be marshalled by scholars who advocate either that culture or nature provided the main agency of modifications in questioned bone assemblages.

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